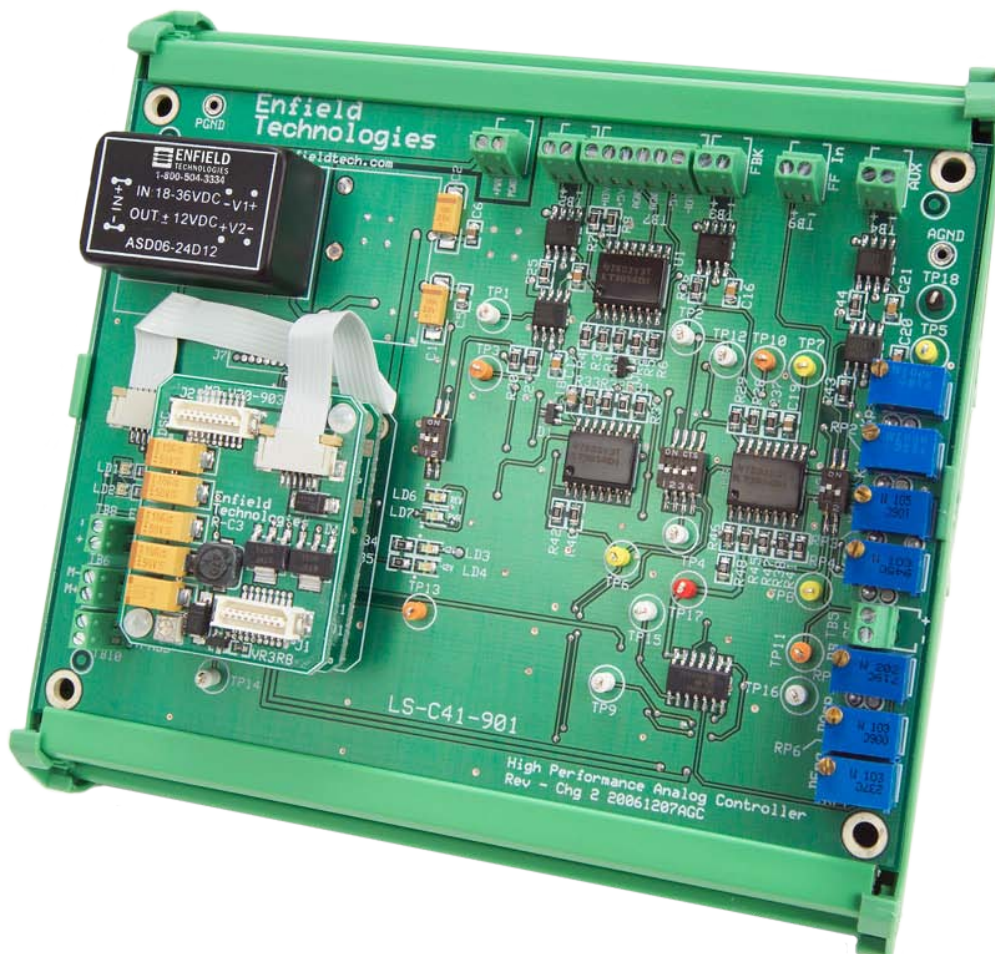




LS-C41

High Performance Analog PID Controller

User's Guide



Contents

Warnings & Notices	2
Overview	3
Physical Components and Layout	4
Factory Setting	5
Position Quick Start Guide	6
Power Connection	7
Command	8
Feedback	9
Valve Tubing and Configurations	10
Potentiometers	11
Screw Terminals	12
Switches	13
Controller Configurations	14
User Interface	15
Test Points	16
Mezzanine Printed Circuit Board	17
Integral Anti-Windup and Reset	18
Driver Disable/Enable	19
Dither Frequency and Amplitude	20
Dead band Elimination	20
Installation and Removal	21
Troubleshooting	23

Warnings & Notices

WARNING:

Installation and operation of electric and high pressure systems (fluids and compressed gas) involves risk including property damage and personal injury or death.

Installers and users should be properly trained or certified and take safety precautions. This product may cause death, personal injury, or property damage if improperly used or installed.

The information in this document and other information from Enfield Technologies and its authorized representatives are intended for use by persons having technical expertise in selecting and using these products. Product owners ("you") should analyze all technical and safety requirements of your specific application, including the consequences of any possible failure, before selecting a product. This product may not be suitable for all applications, such as those acting upon people. Suitability is solely your responsibility. Because the requirements for each application may vary considerably, you are solely responsible for conducting any testing or analysis that may be required to determine the suitability of the product for your application, and to ensure that all performance, safety and warning requirements for your application are met.

Caution:

While the product is low voltage, it is an open-frame electronic component and care should be taken to prevent unintentional contact with the product to avoid damage to person or property.

The LS-C41 is an electro-static sensitive device. Use appropriate electro-static discharge (ESD) procedures during handling and installation.

Notice:

Use and purchase of this product is subject to Enfield Technologies' Terms and Conditions of Sale and Use. Improper installation or use voids warranty. Consult factory regarding special applications. Specifications are subject to change. Reasonable efforts have been made to provide useful and correct information in this document, but this document may contain errors and omissions, and it is subject to change.

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Overview

The LS-C41 is a complete, high-speed, high-accuracy analog control solution for use with Enfield Technologies LS-Series pneumatic valve products. The LS-C41 can provide a 'Nested Loop' control architecture for implementation where complex control solutions are required. The main loop or outer loop incorporates a flexible Proportional Integral Derivative control with an optional and selectable Feed-Forward path. There are several control configurations available by adjusting gains or through DIP switch settings.

All input signals are true differential inputs and have common mode limits that extend beyond the onboard power supply of $\pm 12V$. The input signals for control command (CMD) and all feedback (FBK & AUX) signals must be coordinated (for example; CMD and FBK must both be on a 0-10V format). An efficient PWM-based valve drive is built in to provide the necessary $\pm 1A$ required to position the LS-Series valve. On-board DC/DC converters allow for a single power supply connection of 24VDC. This power supply is protected to prevent damage if the power supply connections are reversed.

Physical Characteristics and Component Layout

The device controller measures 5.25" x 3.92". There are four (4) mounting holes aligned in the corners of the device located 4.85" x 3.60" on center and in a rectangular format. A component placement diagram is shown below.

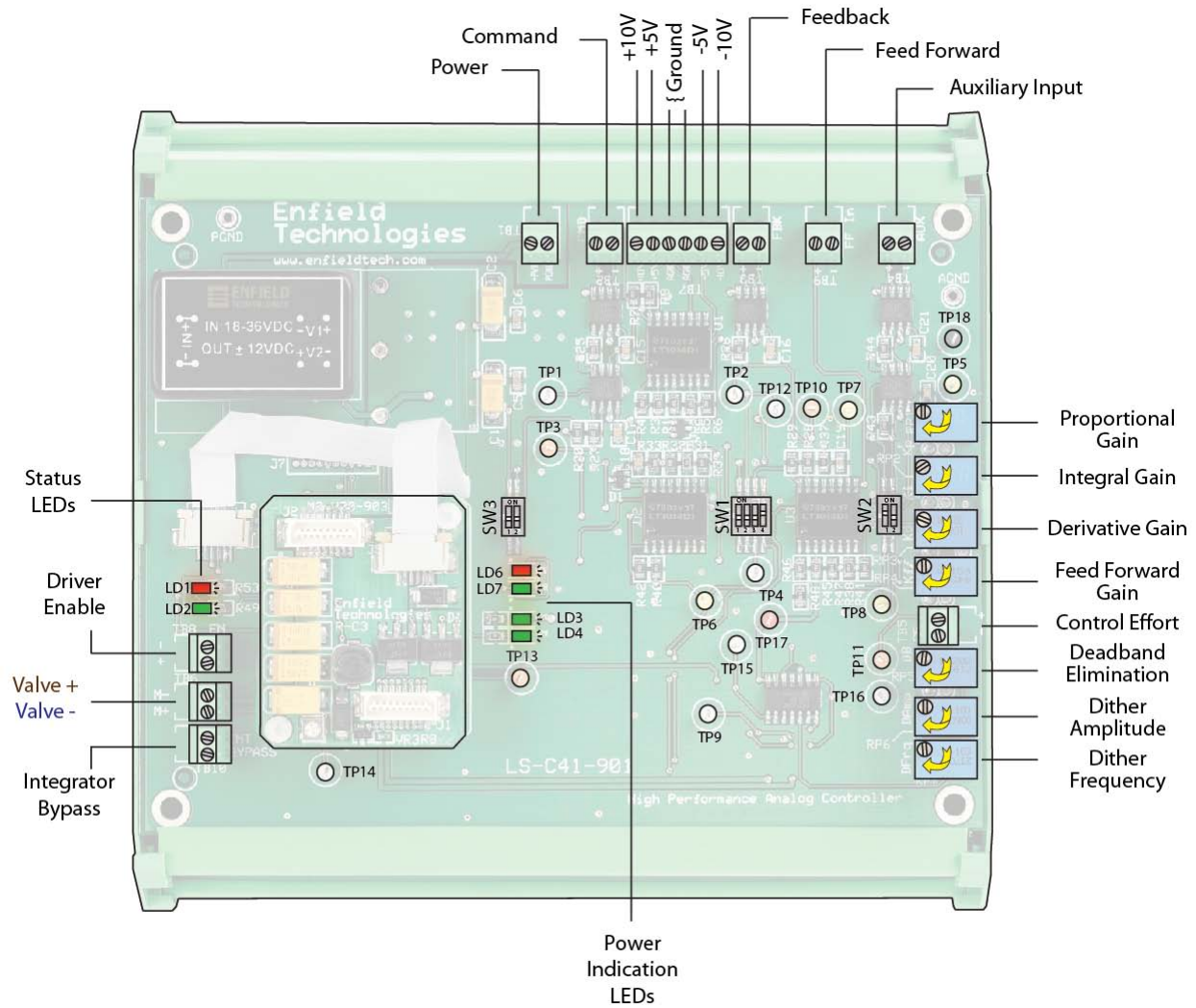


Figure 1 – Component Placement Diagram

Factory Settings

Receipt Inspection & Shipping

CAUTION: ELECTRO-STATIC SENSITIVE DEVICE; USE APPROPRIATE ESD HANDLING PROCEDURES DURING HANDLING AND INSTALLATION.

Upon receipt, ensure the packaging is intact including the Electro-static Sensitive Device (ESD) sticker and packaging. The Device Controller is shipped configured as shown in Tables 1 and 2 (below):

Designation	PCB Label	Description	Initial Setting
RP1	Kp	Proportional Gain Adjustment	2.0 V/V
RP2	Ki	Integral Gain Adjustment	0.0 V/V-s
RP3	Kd	Derivative Gain Adjustment	0.0 V-s/V
RP4	Kff	Feed-Forward Gain Adjustment	0.0 V/V
RP5	DB	Magnitude of Dead-Band Compensation	0%
RP6	Damp	Dither Amplitude Adjustment	Approximately 100mA _{pp}
RP7	DFrq	Dither Frequency Adjustment	Approximately 1 kHz

Table 1 – Factory Potentiometer Settings

Designation	Function	Initial Setting
SW1	Derivative Input Select, Integrator Enable/Disable	SW1-1: Off SW1-2: Off SW1-3: Off SW1-4: On
SW2	Control Effort Select	SW2-1: On SW2-2: Off
SW3	Feed-Forward Input Select	SW3-1: Off SW3-2: Off

Table 2 – Factory Switch Settings

The factory settings result in a P-type controller configuration (see figures 2 and 3) with a proportional gain of 2.0 V/V.

Position System Quick Start Guide

Figure 2 – Standard Position System Setup

Power Connection

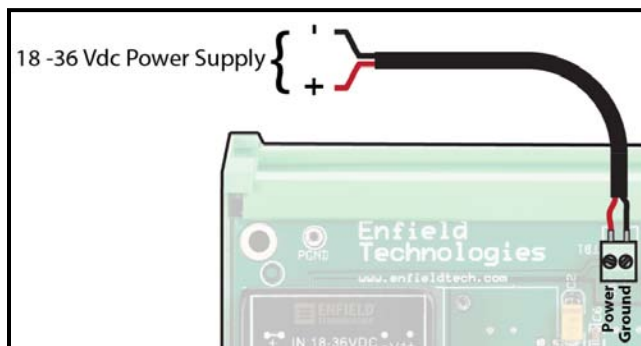


Figure 3 – Power Connection

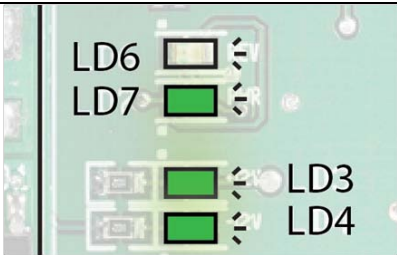
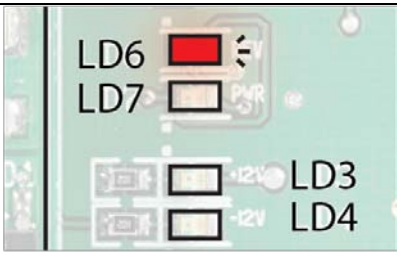
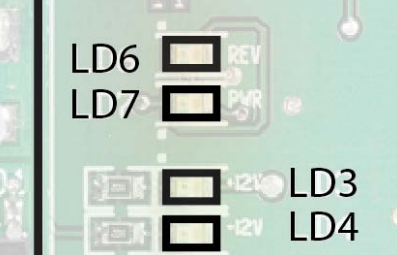
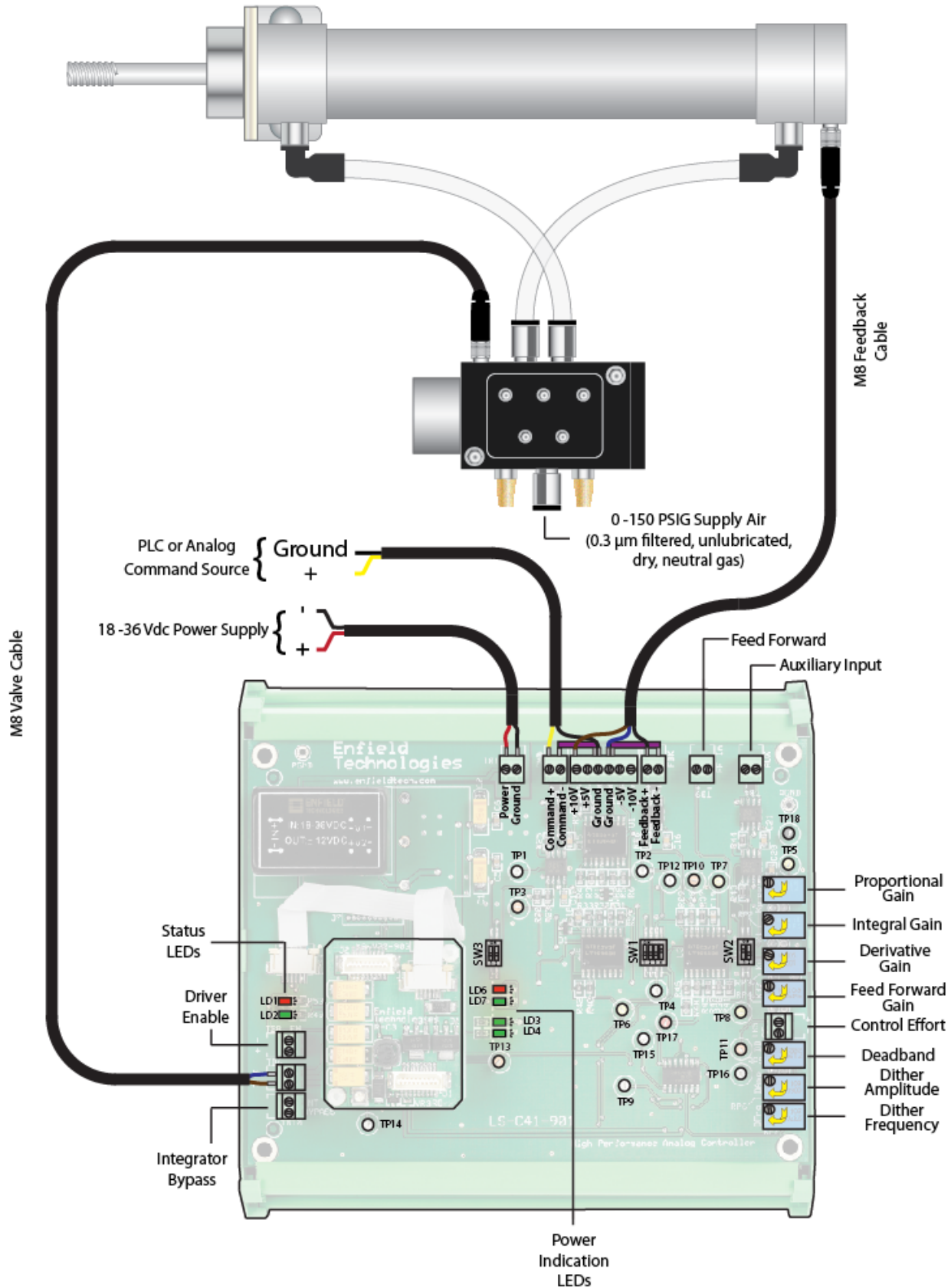
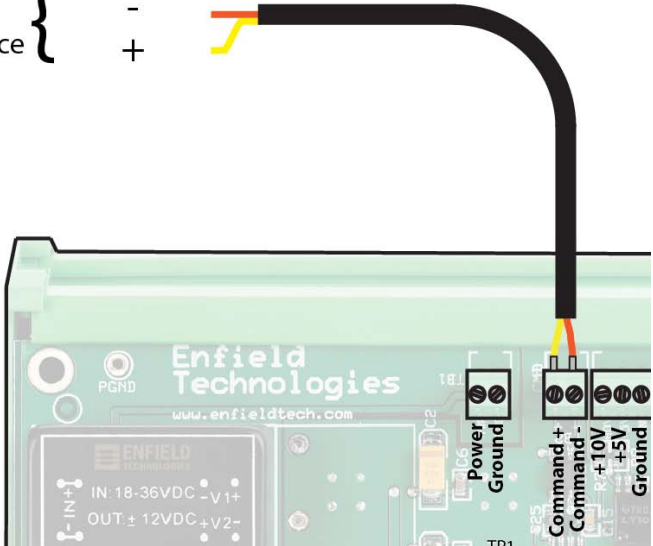
Power Indication LEDs	System Status
	System Is Power Correctly
	Reverse Polarity Solution: Switch power and ground wires going into TB1
	Power not Connected Solution: Ensure power is properly connected

Table 3 – Power Indication LEDs

For more information see the user interface section of the manual.



Command

Desired Input Type	Wiring Configuration
Differential Input	PLC or Analog Command Source { - + 

Position Feedback

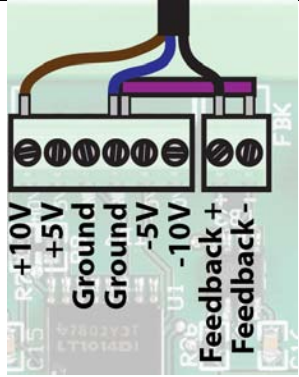
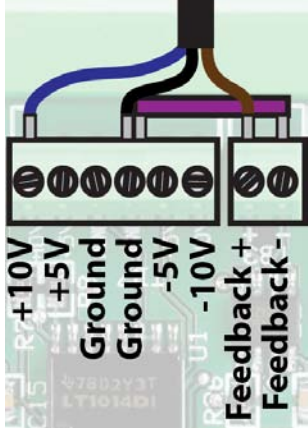
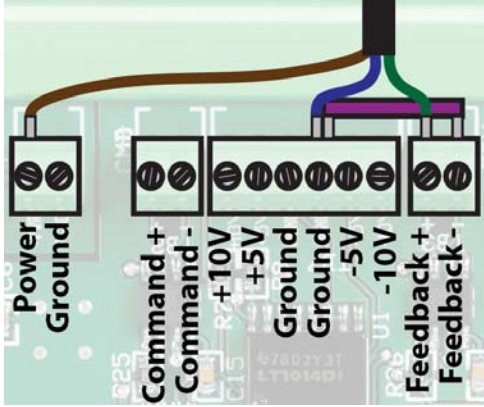
Company	Feedback Configuration
 Note: Configuration Shown with Enfield Technologies' LS-Cable. Insert Jumper Between Ground and 'Feedback -'	 The diagram shows a cable connector with 10 pins. The pins are labeled from left to right: +10V, +5V, Ground, Ground, -5V, -10V, Feedback +, and Feedback -. A purple jumper is shown connecting the third pin (Ground) to the seventh pin (Feedback -).
 Note: Configuration Shown with Enfield Technologies' LS-Cable. Insert Jumper Between Ground and 'Feedback -'	 The diagram shows a cable connector with 10 pins. The pins are labeled from left to right: +10V, +5V, Ground, Ground, -5V, -10V, Feedback +, and Feedback -. A purple jumper is shown connecting the third pin (Ground) to the seventh pin (Feedback -).
 Note: Configuration Shown with Balluff Cable. Insert Jumper Between Ground and 'Feedback -'	 The diagram shows a cable connector with 12 pins. The pins are labeled from left to right: Power Ground, Command +, Command -, +10V, +5V, Ground, Ground, -5V, -10V, Feedback +, and Feedback -. A purple jumper is shown connecting the sixth pin (Ground) to the tenth pin (Feedback -).

Table 5 – Feedback Signal Configurations

To verify that the feedback input has been connected correctly, measure the voltage at TP2 with reference to ground. For more information as well as the location of the test points see Figure 8.

Valve Tubing and Cable Configurations

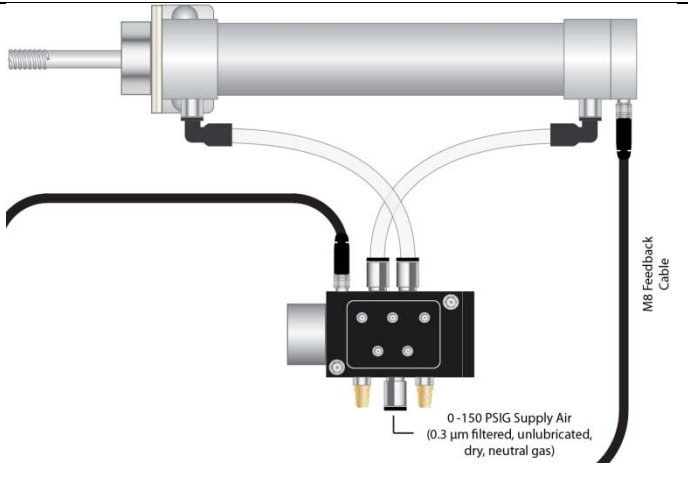
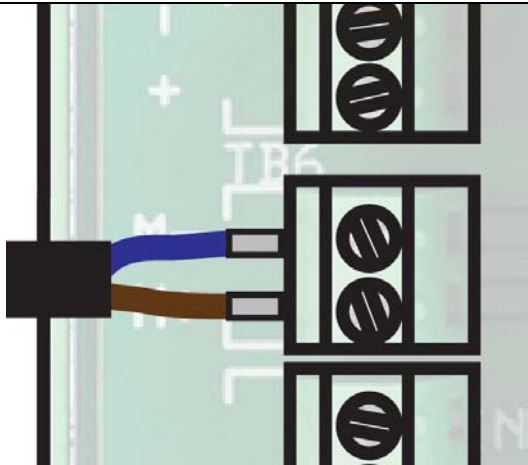
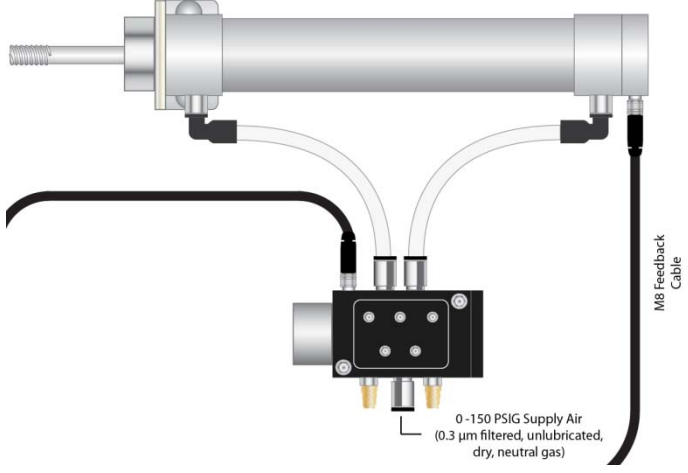
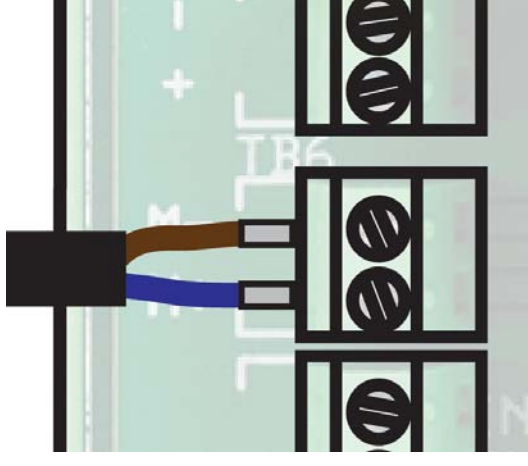
Tubing Configuration	M8 Valve Cable Configuration
	
	

Table 6 – Valve Tubing and Cable Configurations

Potentiometers

All adjustments are by 25-turn potentiometers that are located on the right portion of the PCB (RP1 through RP7). The controller potentiometers (RP1-RP4) are on the middle-right and the valve-management potentiometers (RP5-RP7) are located on the lower-right. The potentiometer adjustments are as shown in 7 below.

Designation	PCB Label	Description
RP1	Kp	Proportional Gain Adjustment - Range: 0.0 → 100.0 V/V
RP2	Ki	Integral Gain Adjustment - Range: 0.0 → 100.0 V/V-s
RP3	Kd	Derivative Gain Adjustment - Range: 0.0 → 1.0 V-s/V
RP4	Kff	Feed-Forward Gain Adjustment - Range: 0.0 → 1.0 V/V
RP5	DB	Dead-Band Compensation - Range: 0% → 25%
RP6	DAmpl	Dither Amplitude Adjustment - Range: 0.0 to ±0.25A
RP7	DFrq	Dither Frequency Adjustment - Range: 10 Hz to 4 kHz

Table 7 - Potentiometer Adjustments

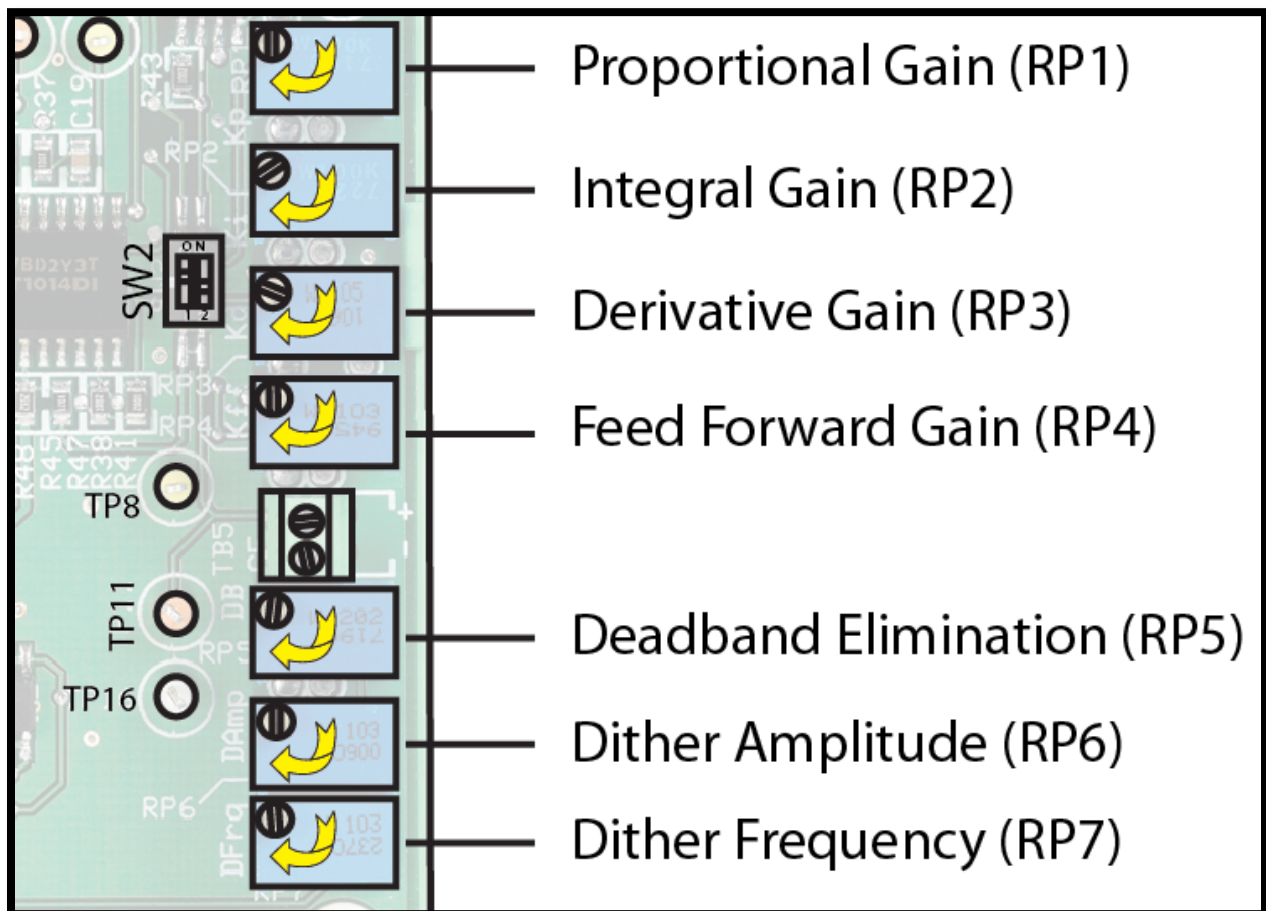


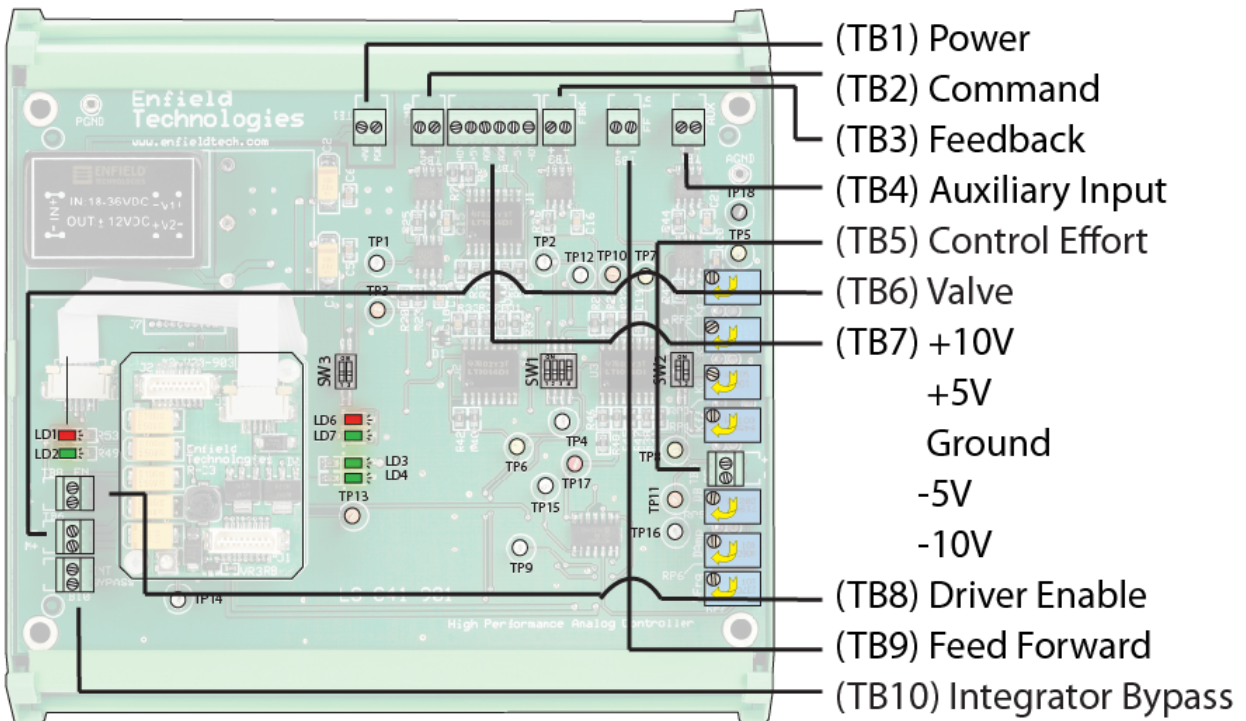
Figure 4 – Potentiometers

Screw Terminals

There are eight (8) 2-pin connectors and a single six (6) pin connector; connections to the device controller are made via screw terminals. The list of connections and designations are provided in 8 below.

Designation	PCB Label	Pin Designation	Description
TB1	+PWR, PGND	Pin 1: +24VDC Pin 2: PGND	+24VDC Power Connection
TB2	CMD	Pin 1: + Command Pin 2: - Command	Differential Input Signal for Command Input
TB3	FBK	Pin 1: + Feedback Pin 2: - Feedback	Differential Input Signal for Feedback Input
TB4	AUX	Pin 1: + Auxiliary Pin 2: - Auxiliary	Differential Input Signal for Auxiliary Feedback Input
TB5	CE	Pin 1: + Control Effort Pin 2: - Control Effort	Output Signal for Control Effort Level; Pin 2 is Common with AGND
TB6	M±	Pin 1: + Motor Current Pin 2: - Motor Current	Output for Enfield Technologies LS-Series Valve Coil; PWM High Power Output;
TB7	+10V, +5V, AGND, -5V, -10V	Pin 1: + 10VDC Ref. Pin 2: + 5VDC Ref. Pins 3, 4: AGND Pin 5: - 5VDC Ref. Pin 6: - 10VDC Ref.	Reference Voltages for Sensor Excitation, Signal Input Source, or other uses. Low Current Output (10mA each).
TB8	EN		Short Pin 1 to Pin 2 to disable driver (see Driver Disable/Enable section)
TB9	FF In	Pin 1: + Feed-Forward Pin 2: - Feed-Forward	<u>Single-ended</u> FF input; Un-buffered; ±10V
TB10	INT BYPASS		Short Pin 1 to Pin 2 to reset integrator. (see Integral Anti-Windup and Reset section)

Table 8 - External Connections and Designations



Switches

Three sets of DIP switches mounted on the PCB allow for a wide variety of control system configurations for a multitude of applications. The DIP switches and their functions are listed in Table 9. A brief description of the various control configurations is provided in the 'Configuration' section.

Designation	Function	Description
SW1	Derivative Input Select, Integrator Enable / Disable	Switches 1-1 through 1-3 select the signal source for the derivative: SW1-1: Error; Used in PD and PID SW1-2: AUX; Used when the derivative of other inputs is beneficial SW1-3: FBK; Used if only feedback derivative is desired without the command input effect Switch 1-4 is used to bypass the integrator (I) in the PID controller: SW1-4: Integrator bypass; can be used to reset the time history of the integrator. It is also recommended to enable this switch when the integrator is not being used for control (for example, in a P or PD controller).
SW2	Control Effort Select	Selects the signal source for the on-board valve driver: SW2-1: PID Output; Used for conventional PID SW2-2: Nested Loop Controller; Used when the Nested Loop Function is used
SW3	Feed-Forward Input Select	Selects the signal source for the feed-forward: SW3-1: CMD; Used when control effort is directly proportional to the command input SW3-2: Aux FF; Used when the control effort is directly proportional to some other input signal.

Table 9 - DIP Switch Configuration Settings

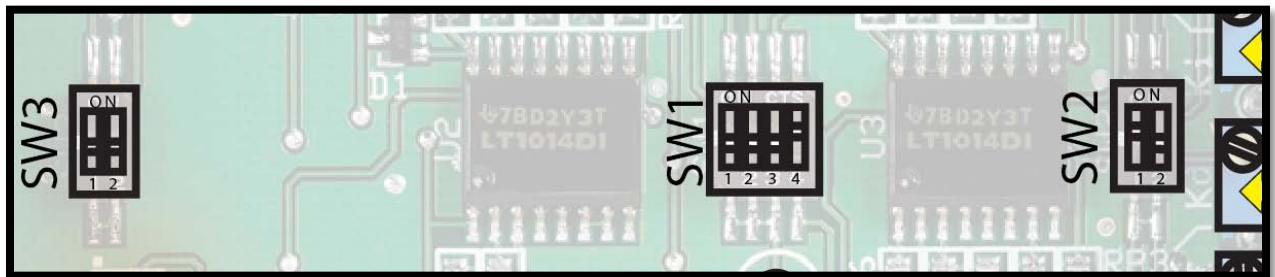


Figure 6 - Switches

Controller Configurations

The LS-C41 Device Controller is extremely flexible; by configuring a selection of DIP switches and adjusting an array of potentiometers, a wide range of control and drive configurations can be selected. This section will address several of the different control architectures possible with this Device Controller. Other configurations may be possible and could be safely implemented; however, please consult the manufacturer prior to utilizing the Device Controller in any configuration not listed here.

	Designation		Position/Condition	Notes
P-Type Proportional Control System (Factory Settings)	SW1	SW1-1	Off	Derivative Gain Not Needed
		SW1-2	Off	Derivative Gain Not Needed
		SW1-3	Off	Derivative Gain Not Needed
		SW1-4	On	Integral Gain Not Needed
	SW2	SW2-1	On	Aligns Proportional Output to Driver
		SW2-2	Off	Not Required
	SW3	SW3-1	Off	Not Required
		SW3-2	Off	Not Required
PD-Type Proportional Derivative Control System	SW1	SW1-1	On	Aligns Error to Derivative
		SW1-2	Off	N/A
		SW1-3	Off	N/A
		SW1-4	On	Integral Gain Not Needed
	SW2	SW2-1	On	Aligns Proportional Output to Driver
		SW2-2	Off	Not Required
	SW3	SW3-1	Off	Not Required
		SW3-2	Off	Not Required
PI-Type Proportional-Integral Control System	SW1	SW1-1	Off	N/A
		SW1-2	Off	N/A
		SW1-3	Off	N/A
		SW1-4	Off	This will enable Integral Gain
	SW2	SW2-1	On	Aligns Proportional Output to Driver
		SW2-2	Off	Not Required
	SW3	SW3-1	Off	Not Required
		SW3-2	Off	Not Required
PID-Type Proportional-Integral-Derivative Control System	SW1	SW1-1	On	Aligns Error to Derivative to create a PID Controller
		SW1-2	Off	N/A
		SW1-3	Off	N/A
		SW1-4	Off	This will enable Integral Gain
	SW2	SW2-1	On	Aligns Proportional Output to Driver
		SW2-2	Off	Not Required
	SW3	SW3-1	Off	Not Required
		SW3-2	Off	Not Required

Table 10 – Control Types

User Interface

The LS-C41 is equipped with four power indication LEDs as well as two status LEDs. Upon successful powering of the device, the PWR, +12V, and -12V green LEDs (located toward the center of the main circuit board) will light. If power connections were reversed, the red REV LED will be lit. Additionally, the both status LEDs (located toward the left-hand side of the main circuit board) will light green¹ for one second, after which they will light amber for one second. After this sequence, the states of these two LEDs describe the operation of the Device Controller, as outlined in Table 11.

LD1 (top LED)	LD2 (bottom LED)	Condition
Off	Off	Normal Operation
Blinking Amber (Quickly)	Any	Short Circuit Fault
Blinking Green (Slowly)	Any	Open Circuit Fault
Any	Green (Solid)	Reference Voltage Error
Any	Amber (Solid)	Symmetry fault

Table 11 – Status LEDs

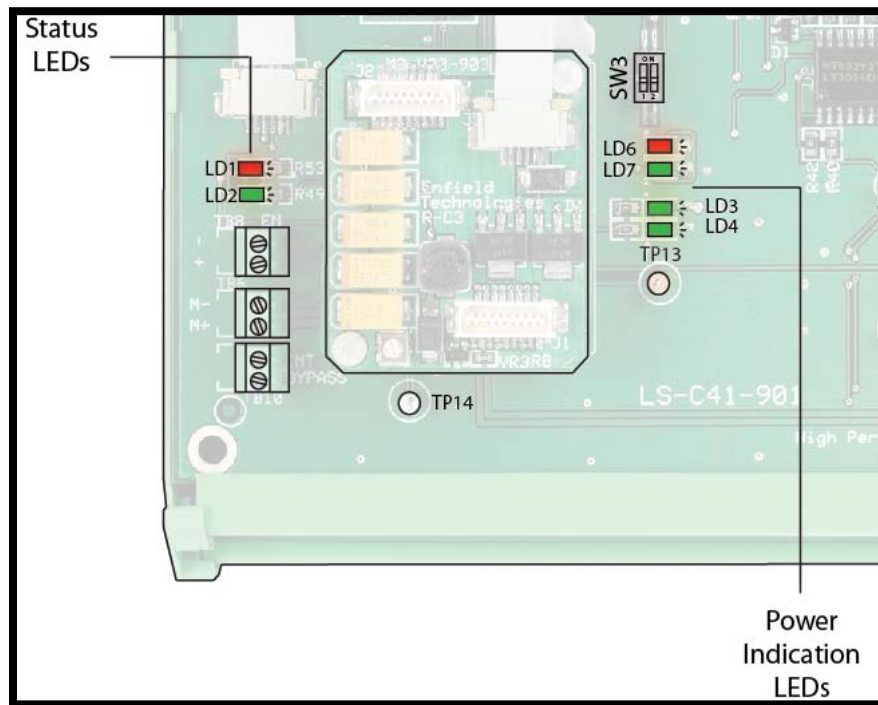


Figure 7 - LEDs

¹ Note: "Green" may be green, blue, or violet, based on current production. Likewise, "amber" may be amber, yellow, red, or orange.

Test Points

Several test points are provided on the Device Controller for tuning analysis and troubleshooting. Some test points will only be active under certain configurations (see later sections).

Test Point	Color	Function	Description
TP1	WHT	Command Input	Command Input Level after the Differential Buffer; -10V to +10V
TP2	WHT	Feedback Input	Feedback Input Level after the Differential Buffer; -10V to +10V
TP3	ORG	Control Error	$TP3 = TP1 - TP2$; -10V to +10V
TP4	WHT	Derivative Input	Based on SW1 Settings - See PD Configuration; -10V to +10V
TP5	YEL	'P' Gain Output	$TP5 = K_p * TP3$; -10V to +10V
TP6	YEL	'I' Gain Output	$TP6 = K_i * [\text{Integral of } TP3]$; -10V to +10V
TP7	YEL	'D' Gain Output	$TP7 = K_d * [\text{Derivative of } TP4]$; -10V to +10V
TP8	YEL	'FF' Gain Output	$TP8 = K_{ff} * TP1$ or $K_{ff} * FF$; -10V to +10V;
TP9	WHT	Dither Frequency	Dither Frequency Status (0-5V range)
TP10	ORG	PID + FF Output	Algebraically Summed Outputs of TP5, 6, 7, and 8
TP11	ORG	Control Effort #1	Analogous to Valve Input Level; -10V to +10V
TP12	WHT	Auxiliary Input	Auxiliary Input Level after the Differential Buffer; -10V to +10V
TP13	ORG	Control Effort #2	Similar to TP11 After Scaling and Level-Shifting; 0V to +5V scale
TP14	WHT	Coil Current	Coil Current Signal; 0 to +5V with 2.5V Reference; 2.0 V/A
TP15	WHT	Dither Amplitude	0-250mA _{on} amplitude; 0-5V range
TP16	WHT	Dead Band	Dead Band Elimination Status; 0-25% (0-5V range)
TP17	RED	+Vref	Positive Reference Voltage; 2.500V Nominal
TP18	BLK	AGND	Analog Ground Connection

Table 12 - Description of Test Points Available on the Device Controller

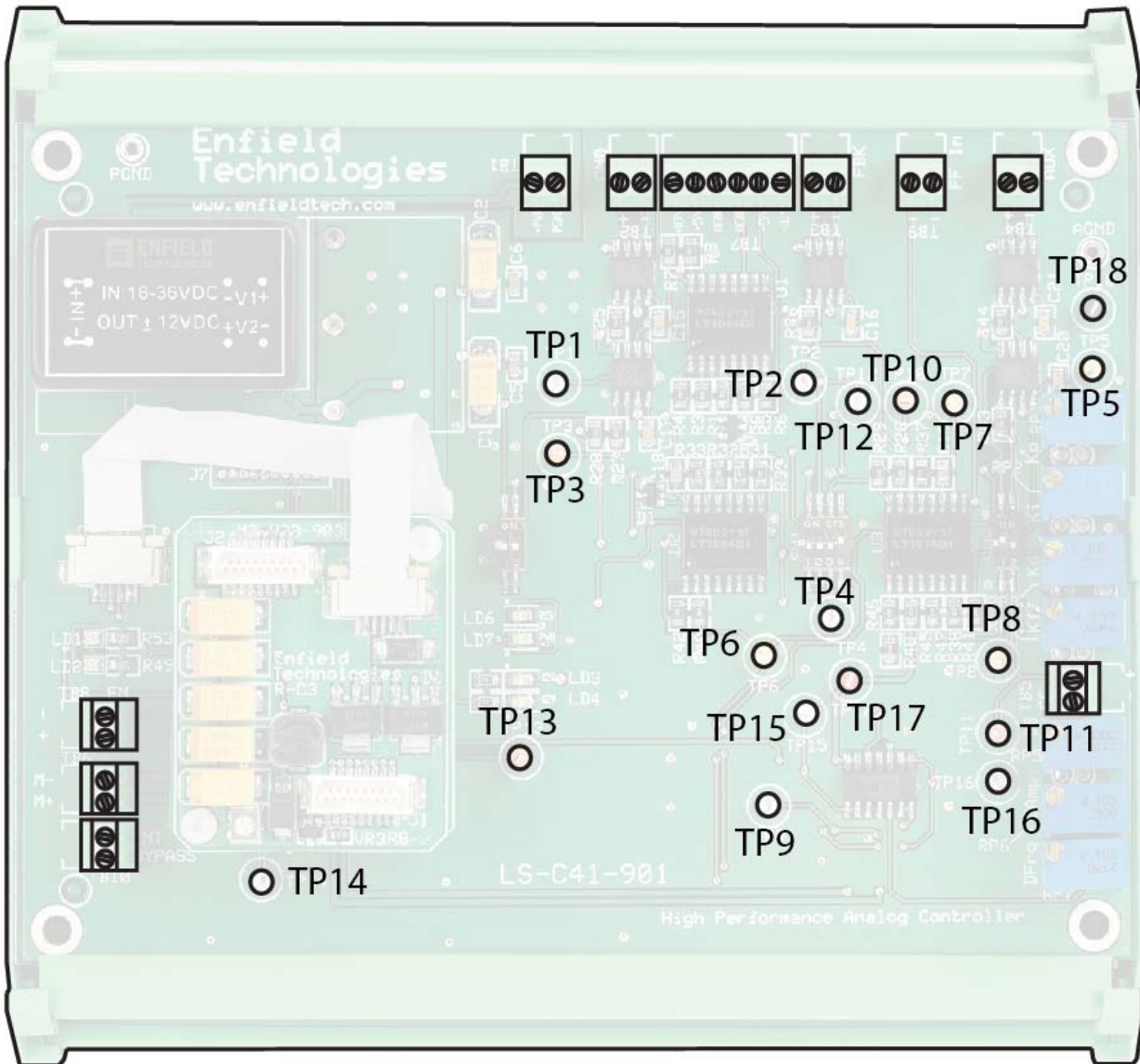


Figure 8 - Test Points

Mezzanine Printed Circuit boards

The M2-V30-901 and M2-V30-903 boards (located on the lower left-hand corner of the main circuit board) are a key element in the LS-C41. These circuit boards provide power and driver functionality and have no user adjustments on them. These boards are installed to the main circuit board with 2-56 hardware for vibration resistance. Power is delivered to these boards via a flexible cable; the user must not tamper with this cable, as doing so will lead to unexpected operation of the Device Controller and any device attached to it.

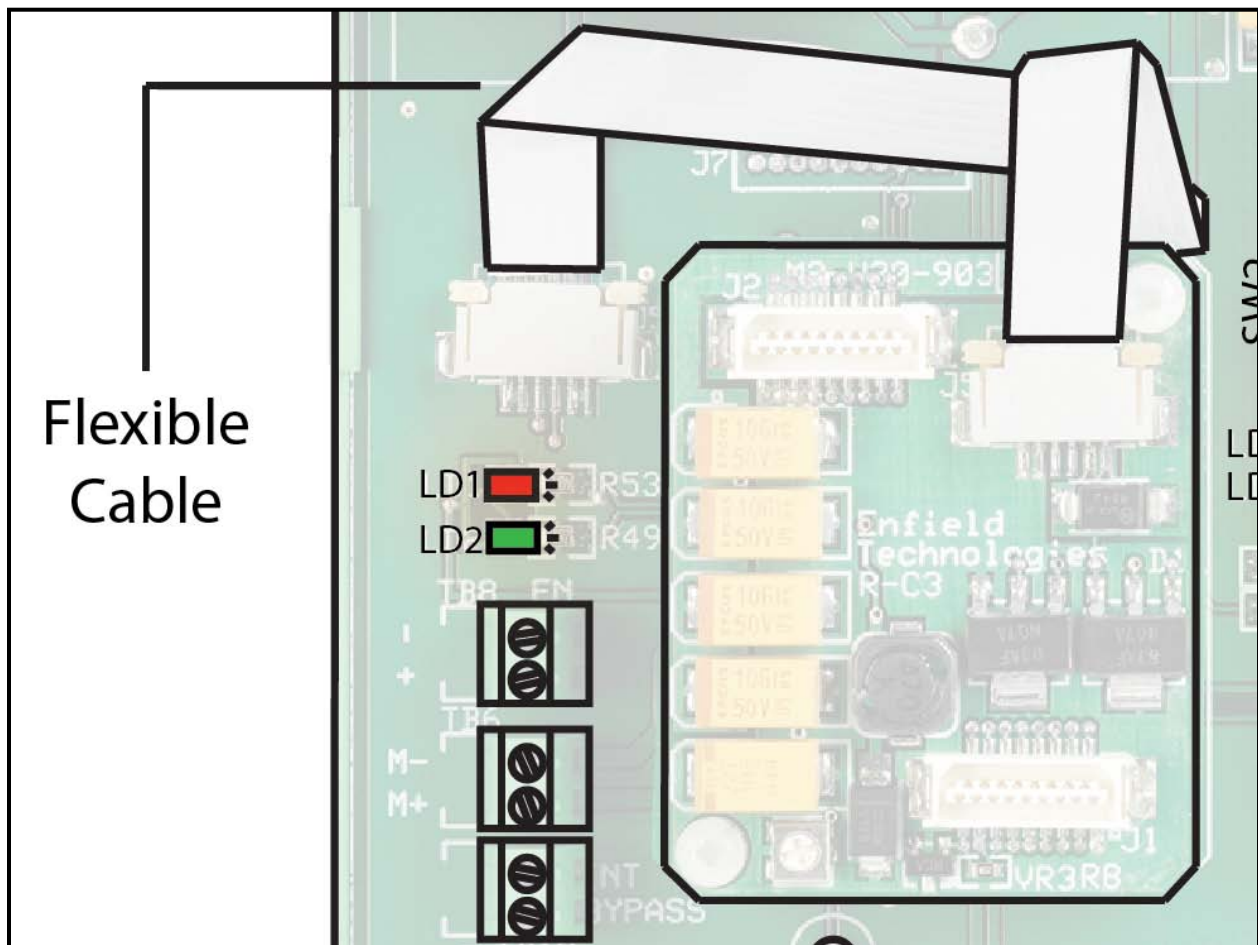


Figure 9 – Mezzanine Printed Circuit Boards

Integral Anti-Windup

The integral control circuit in the LS-C41 contains an anti-windup sub circuit which prevents the integrator from building up indefinitely when the control output becomes saturated. Additionally, the Device Controller contains an integrator reset switch (SW1-4), which resets the time history of the integrator when the user turns it on and then off. If SW1-4 is left in the “reset” or “on” position, or if TB10 is shorted, the integrator will remain disabled. The switch must be switched “off” in order for the integrator to be active.

Remote Integral Reset

The integral portion of the controller can be remotely reset by using a relay to short TB10 as shown below. **WARNING:** Do not attempt to ground TB10 or excite it with a voltage as this may cause permanent damage to the driver.

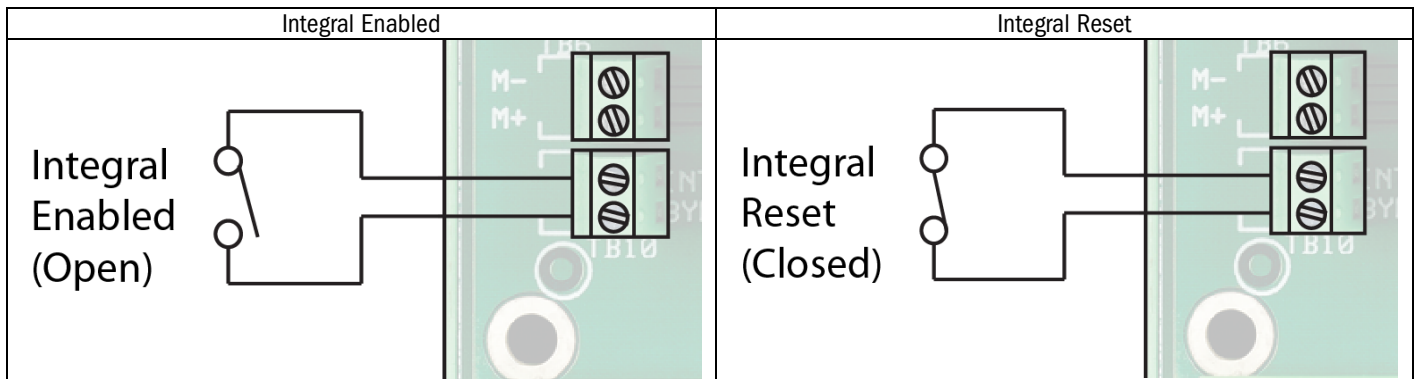


Figure 10 – Integral Reset

Driver Disable/Enable

The driver can be disabled by using a relay to short TB8 as shown below. **WARNING:** Do not attempt to ground TB8 or excite it with a voltage as this may cause permanent damage to the driver.

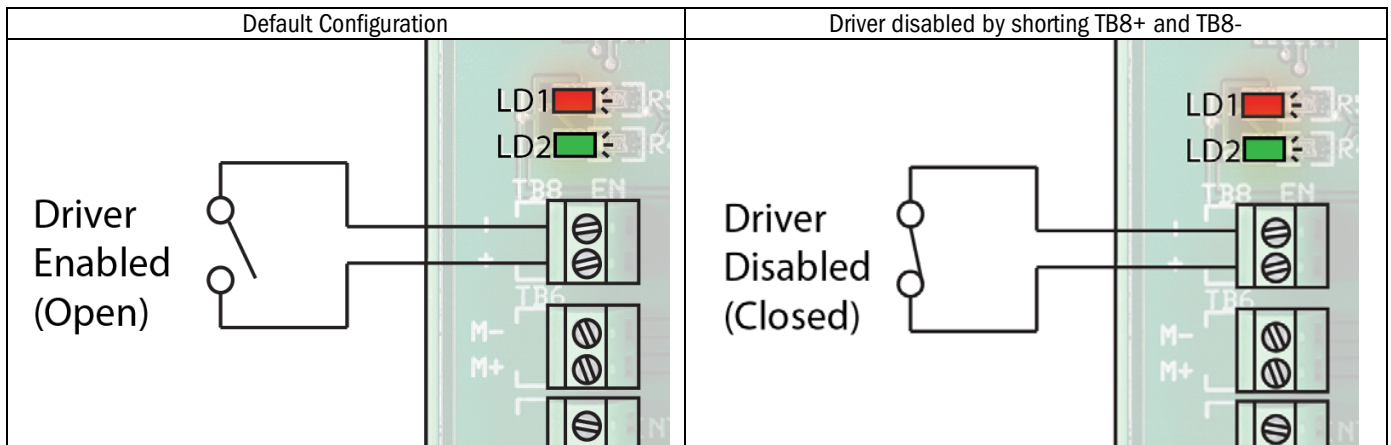


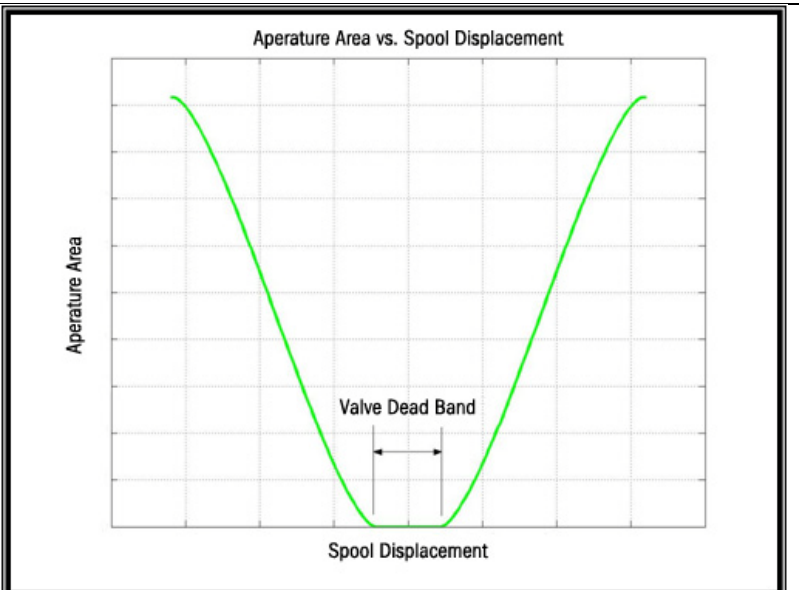
Figure 11 – Driver Enable/Disable

Dither Frequency and Amplitude

The potentiometer dial marked RP6 DAmP provides a square wave dither with variable frequency (10 Hz to 4 kHz set by RP7 DFrq) to the valve spool. At its maximum setting (fully CW), a high pitched tone will be audible from the valve which is a high speed vibration added to the valve aperture gate (spool). The displacement of this vibration is so small and fast as to have an imperceptible affect on pressure or flow output. However, this dither helps minimize the effects of static friction in the spool and thus improves the system's overall performance.

Deadband Elimination

RP5 adjusted fully CCW. This is the factory default setting. This setting would make the valve resistant to small changes in command.



RP5 adjusted to electrically remove deadband from the valve. By removing the deadband, the valve would be very sensitive to small changes in command.

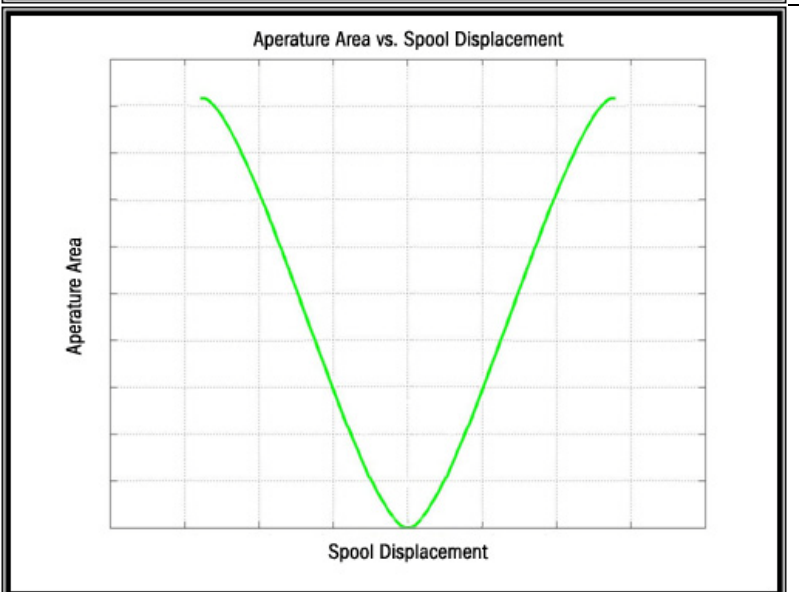


Table 13 – Deadband

Installation & Removal

W A R N I N G

THESE PRODUCTS MAY CAUSE DEATH, PERSONAL INJURY, OR PROPERTY DAMAGE IF THEY ARE IMPROPERLY USED OR INSTALLED

The information in this document and other information from Enfield Technologies and its authorized representatives are intended for use by persons having technical expertise in selecting and using these products. You should analyze all technical and safety requirements of your specific application, including the consequences of any possible failure, before selecting a product. These products are not suitable for all applications, such as applications related to or connected with aviation, aircraft, or aerospace. Because the requirements for each application may vary considerably, you are solely responsible for conducting any testing or analysis that may be required to determine the suitability of the product for your application, and to ensure that all performance, safety and warning requirements for your application are met.

These products are subject to Enfield Technologies' Limited Warranty which sets forth your sole and exclusive remedy in the event any products are defective in workmanship or material. Enfield Technologies shall have no liability for any property damage, personal injury, or other loss or damage (including incidental, special, and consequential damages) resulting from the improper selection, installation, or use of any product.

The Device Controller is mounted in a plastic DIN housing; therefore, it can be directly mounted to a DIN rail. Alternatively, it can be mounted using 4-40 screws and suitable stand-offs. There are four (4) mounting holes aligned in the corners of the device located 4.85" x 3.60" on center and in a rectangular format.

Install the Device Controller as follows:

CAUTION: ELECTRO-STATIC SENSITIVE DEVICE; USE APPROPRIATE ESD HANDLING PROCEDURES DURING HANDLING AND INSTALLATION.

- Install the Device Controller on a DIN rail or using the four (4) mounting holes provided.
- Connect pneumatic valve to pneumatic system with appropriate port adapters and plumbing. Ensure that the valve is connected in such a way that the system is safe, even in the event of unexpected valve operation.
- Connect all signal and power connections to the appropriate connectors on the Device Controller.
- Connect the LS-Series cable to/from the LS-C41. When connecting a valve to the LS-C41, it should be done with the color convention shown in Table 13 (below):

Wire Color	Connection Point
Brown	TB6-1: M+
Blue	TB6-2: M-

Table 14 – Valve-Controller Connections

- Configure and tune the controller as required for specific application.

Remove the Device Controller as follows:

CAUTION: ELECTRO-STATIC SENSITIVE DEVICE; USE APPROPRIATE ESD HANDLING PROCEDURES DURING HANDLING AND INSTALLATION.

- Remove electrical power from the Device Controller.
- Disconnect all signal connections from the Device Controller.
- Remove product from DIN rail or remove the four (4) mounting screws.
- Package the Device Controller in appropriate ESD packaging (the original packaging is preferred).

Start-Up & Shutdown

- Ensure that the valve is connected in such a way that the system is safe, even in the event of unexpected valve operation.
- Apply or remove electrical power to the Device Controller.
- Ensure that the valve is properly connected to the Device Controller on startup to ensure proper controller operation.
- Do not attempt to change the valve while power is applied to the Device Controller; if changing the valve connected to the Device Controller, follow these steps:
 - Ensure that your application will remain safe before making any change (powering down, removing valve, powering on, etc) even in the event of unexpected valve operation.
 - Remove power from the Device Controller.
 - Disconnect the valve from the Device Controller.
 - Connect the new valve to the Device Controller.
 - Apply Power to the Device Controller.

Calibration & Periodic Maintenance

The Device Controller does not require periodic calibration. Periodic tuning of the control system may be required due to physical changes (friction, machine and/or parts wear, etc) in the system under control. Keep the LS-C41 free from dirt, debris, and excessive moisture.

Decommissioning & Corrective Maintenance

The device controller is not serviceable in the field. If corrective maintenance is required, contact the manufacturer for return authorization; 1 800 504 3334.

Troubleshooting

8 Most common problems or concerns:

- Power not applied properly,
 - Power supply not regulating/maintaining acceptable supply voltage levels
 - DC Common wires not connected; improperly connected
- Improper Tuning
 - "P" Gain at 0%
- Inverted polarity
 - Incorrect drive current cable wiring
 - Improper mechanical system connection
- Incorrect Feedback System Connection
- Incorrect/inadequate Command or Feedback signal
- Noise
- Improper Wiring
- Lack of DC Common reference

Symptom	Probable Causes	Corrective Action
System Totally Unresponsive	Power Not Applied	Apply Power, check all power wiring
	"P" Gain at 0.0%	Increase "P" Gain
	Inverted Polarity	Verify signal wiring and drive current wiring polarity; also verify mechanical system polarity and feedback sensor polarity
	Signal Wiring	Verify all wiring is as shown in application examples and as described in the "Installation" section of this document
System Mildly Responsive or Sluggish	Gain too low	Increase "P" Gain
	Power supply voltage not stable	Check power wiring; change power supply
System 'Pegs' or 'Rails'	No Feedback Signal	Connect Feedback Signal
	Feedback Connected Improperly	Verify all wiring is as shown in application examples and as described in the "Installation" section of this document
System Fails to Converge or is Inaccurate	Incorrect Wiring	Verify all wiring is as shown in application examples and as described in the "Installation" section of this document
	Electro-mechanical device requires dither	Increase Dither Amplitude
System Oscillates	Gain too high	Decrease "P" Gain
System 'Buzzes'	Input Signal Noise (possibly 60Hz)	Verify that large or high power machinery is not operating nearby. Also, verify input signal integrity by examining the signal with an oscilloscope.
	Input Signals not connected	Verify all wiring is as shown in application examples and as described in the "Installation" section of this document
	DC Common not connected	Verify all DC common connections are as shown in application examples and as described in the "Installation" section of this document
High Pitched Tone or Whine from Electro-mechanical device	Dither	This is an artifact of the built-in dither and is intended to keep the electro-mechanical device in constant motion. If system performance remains satisfactory, Dither Amplitude may be adjusted to minimize or eliminate this sound.

Table 15 - Troubleshooting